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Breeding Ecology and Behavior of Kittlitz's Murrelet in Kodiak National Wildlife Refuge, Alaska: 2016 Final Report

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USFWS, Kodiak Refuge

Kodiak National Wildlife Refuge
2017

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Timothy W. Knudson[1], Robin M. Corcoran[2], Katelyn A. Stoner[2], M. James Lawonn[3], James R. Lovvorn[1], John F. Piatt[4], and William H. Pyle[2]

Abstract

The Kittlitz's murrelet (*Brachyramphus brevirostris*) is a rare seabird inhabiting coastal areas in Alaska and Eastern Russia. Very little is known about the species annual survival, winter range, and juvenile recruitment. This cryptically colored Alcid lays a single egg in rocky mountainous terrain at a wide range of elevations. The 2016 field season marked the ninth consecutive year researching this species' breeding ecology and behavior in a remote area on southwest Kodiak Island, Alaska. Mountain slopes with sizeable areas of scree and talus were systematically searched for nests between late May and mid-July. This season the size of the research team was doubled so that two of the four study sites could be searched simultaneously, and it was hoped increase the number of nests located. We placed digital game cameras at nest sites to monitor nest fate, incubation shifts, chick feeding rates, and predation events. To obtain growth measurements we visited nests at regular intervals throughout chick development. When nests were no longer active we measured habitat characteristics at and near nest sites. During our search effort we discovered 17 active Kittlitz's murrelet nests. Seven of the 17 nests produced chicks, and three successfully fledged young. We obtained growth measurements from five individuals and feeding rates from six chicks including 408 prey deliveries over 104 days monitored. Of the identified prey delivered to chicks 61% were Pacific sand lance (*Ammodytes hexapterus*) the main forage fish species recorded during the study, and the remaining 39% were capelin (*Mallotus villosus*). We recorded 13 depredations, all by red fox (*Vulpes vulpes*). Apparent nest success was 18% in 2016, lower than the 2008-2015 average (24%). In 2012 and 2013, nest success was high (45%) compared to 2008-2011 and 2014-2015, when only 15% of nests were successful. Over the nine year study 146 active nests have been documented with 33 (23%) successfully fledging a chick.

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Introduction

The Kittlitz's murrelet (KIMU, *Brachyramphus brevirostris*) is a rare seabird of the North Pacific. Knowledge of the species nesting ecology was limited to17 nests recorded before 1999. KIMU are a relatively long-lived (15 years) Alcid with an estimated global population of at least 33,600 (Federal Register 2013). About 70% of KIMU nest in coastal Alaska and 30% in eastern Russia. Concern for this species arose due to its small population, patchy distribution, appearance of decline throughout all or part of its range, and observed low reproductive success in the most important breeding areas (Day et al. 1999, Day and Barna 2007). Despite at-sea survey data indicating annual declines of 30% between 1989 and 2000, more recent data indicated that populations stabilized or were declining at a much slower rate, and no single stressor, or combination of stressors, has been identified as having a population- or species-level impact on this widely distributed species (Federal Register 2013). Factors such as vessel traffic, gill-net bycatch, and oil pollution may have contributed to KIMU declines in the past. However, local influences do not seem adequate to explain recent declines because many species, geographically separated by continents and oceans, experienced similar trends. Large scale stressors that may have contributed to KIMU declines include changes in marine forage fish communities, loss of foraging and/or nesting habitat due to glacial recession, effects of environmental contaminants, and changing patterns in avian predation (van Vliet and McAllister 1994, Piatt and Anderson 1996, Kuletz et al. 2003). It is now well recognized that seabird populations can be indicators of regime shifts in marine environments, and can provide insights into effects of climate change and overfishing (Gill 2007, Zador et al. 2013).

The Kodiak National Wildlife Refuge (KNWR), in coordination with U.S. Geological Survey Alaska Science Center, Alaska Maritime National Wildlife Refuge, Region 7 U.S. Fish and Wildlife Service Office of Ecological Services, and Oregon State and Southern Illinois Universities, has been researching the breeding biology of KIMU continuously since 2008. Following the opportunistic discovery of the first nest on Kodiak in 2006 (Stenhouse et al. 2008), researchers used a combination of radar and audio-visual surveys to document high levels of murrelet flight activity in the Kodiak Glacial Refugium at the southwest end of Kodiak Island (Day and Barna 2007). This unique area is characterized by low to mid-elevation ridges and peaks (mostly >600 m) with large, continuous areas of scree and talus. The parent material of these sites is classified as ultramafic rock, a type of igneous rock containing high concentrations of heavy metals and scarce nutrients, the combination of which prevents growth of most plants (Alexander et al. 2006). The few previously documented KIMU nests were typically at high alpine sites where technical climbing gear and expertise were required. The large expanses of sparsely vegetated rocky slopes within the Kodiak study site provided habitat at lower elevations which were more accessible for nesting studies.

The goals of this study were to continue to fill data gaps regarding nesting biology, diets, and breeding habitat requirements of KIMU in Alaska. Our specific objectives for the 2016 field season were to:

1. Locate approximately 20 KIMU nests and measure all aspects of reproductive ecology including nest initiation, chick-rearing and growth, overall nest success, and causes of nest failure.

2. Characterize terrestrial breeding habitat, including aspects of geology, vegetation, and exposure associated with nest sites.
3. Measure components of feeding ecology, including chick meal delivery rates and diet composition.

This report summarizes the ninth year of nesting ecology research of KIMU in KNWR, Alaska. We summarize the results from our systematic nest searches, nest monitoring, and measurement of nesting habitat characteristics collected during the summer of 2016 on southwest Kodiak Island, and compare selected results with those from previous years.

Study Area

Kodiak Island (57.396° N, 153.483° W, land area 8,975 km²) is located in the northern Gulf of Alaska about 150 km southwest of the Kenai Peninsula. The Shelikof Strait, which is only 40-50 km wide, separates Kodiak Island from the Alaska Peninsula mainland to the north. Two non-vegetated land cover types, bedrock and talus, have been regarded as potentially suitable KIMU nest habitat, and make up 5% of the total area (46,700 ha) of Kodiak Island, reaching elevations up to 1,200 m (mostly >600 m). The study area, located in southwest Kodiak Island, encompasses 700 ha of exposed bedrock and talus slopes. Areas searched for KIMU nests were between 5 and 11 km from the ocean. These rocky areas were at elevations ranging from 80 to 471 m, making them accessible to researchers, unlike many areas where the birds nest at high-elevation alpine sites.

Within the study area (Fig. 1), four base camps provided staging points for nest searching and monitoring. Field camps were located close to large areas of ultramafic rock that could be easily accessed with little travel time to the slopes. All camps were accessible by helicopter and one could be reached by float plane; otherwise the area was limited to foot travel. Throughout the field season the research team traveled between study sites to conduct systematic nest searching and monitoring.

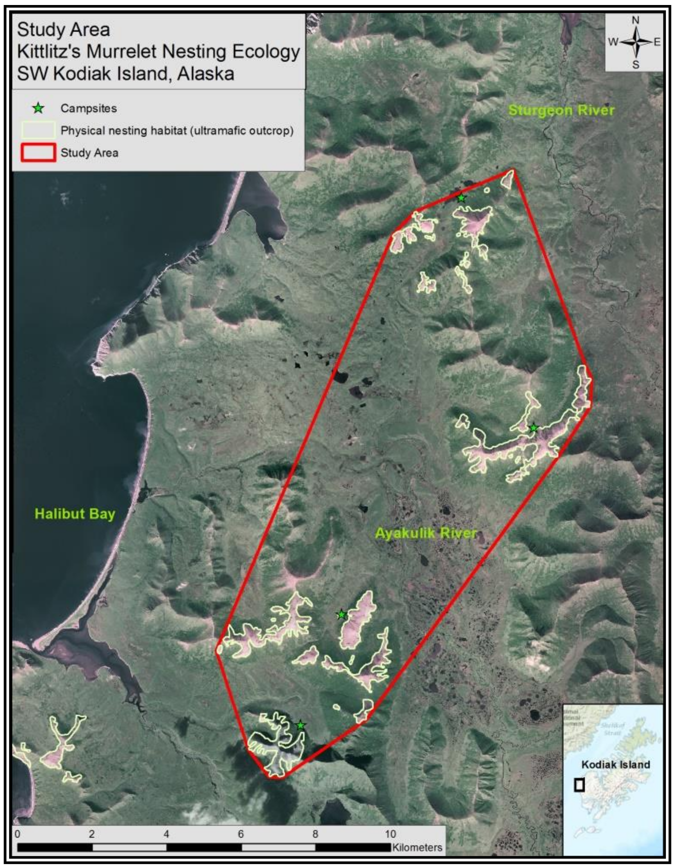

Figure 1. Map of study area on the west side of Kodiak Island, AK.

Methods

Systematic Nest Searching

The nesting habitat consisting of ultramafic rock within each study site was searched to the fullest extent possible within the available time, focusing first on high priority sites (where nests have been found repeatedly), second on medium priority sites (where nests have been found in lower densities), and finally on low priority sites (where nesting habitat existed but the area was not searched previously or, if searched, no nests had been found). Crews systematically searched potential scree nesting habitat with slopes greater than 20°, focusing on steeper slopes and larger patches of ultramafic rock. On the first round of searching four to eight days were spent at each camp covering as much area as possible. During late June, some effort was dedicated to nest monitoring and travel between sites was often dictated by the schedule of nest checks. Nest searching continued until late July when efforts shifted to collecting data on nest site characteristics.

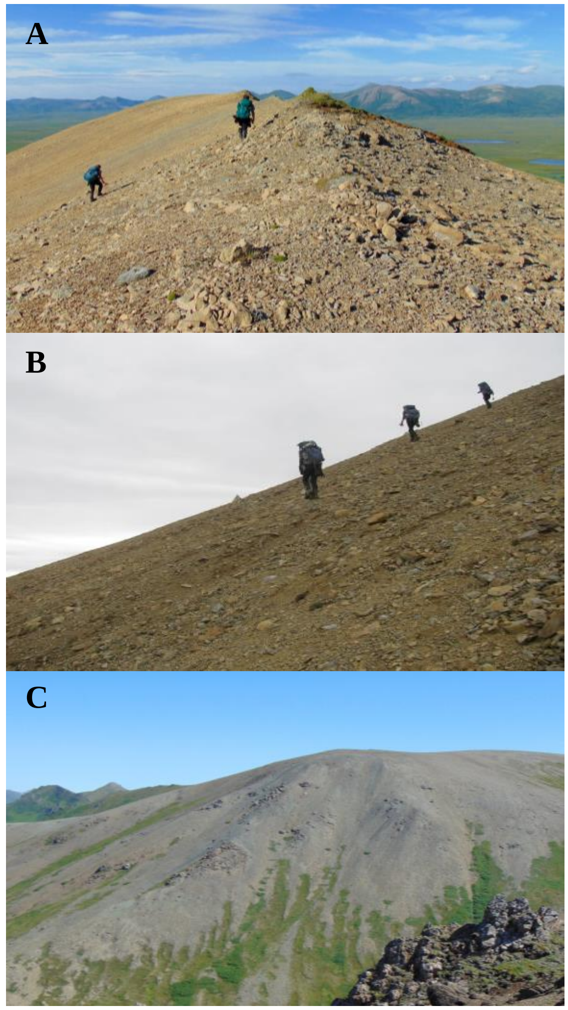

Figure 2. Image A and B show researchers conducting systematic nest searching, and C shows nesting habitat of Kittlitz's murrelet on Kodiak Island, AK.

At the start of each day the research team hiked to the lowest elevation of nesting habitat on the slope to be searched that day. They positioned themselves vertically up the slope with a gap of 5–10 m between each person. The person at the highest elevation led the systematic search. With pin-flags and a GPS unit (Garmin GPSMAP® 76cxs), this lead person walked at a constant elevation, stepping up 2–3 m to drop a flag as reference for the return line. The rest of the search team followed a horizontal distance of 2–3 m behind the lead searcher (to avoid falling rocks and spot flushing birds) and kept a vertical distance of 5–10 m between each searcher (Fig. 2 (A)). The bottom searcher stayed about 2 m above the flags that were dropped on the preceding transect, walking down to collect each flag before returning to the current line. When the searchers reached the end of a line, they moved up and reversed course, systematically searching the entire area to the ridge top. All tracks were logged using a GPS unit.

Flushing an adult from the nest was by far the most common method of discovery. Occasionally lone chicks were found while searching and adults were spotted on the ground prior to flushing. Adults tended to flush and fly directly downslope, hugging the slope of the mountain. Flushing adults were identified as a KIMU based on the outer white rectrices characteristic of this species.

Once the flushing adult was out of sight, attention was immediately focused on finding the single egg camouflaged among the rocks.

Procedures at the Nest

Once a nest was discovered, each person put on nitrile gloves to minimize scent around the nest and proceeded with an assigned task. One person photographed the area and recorded data, another set up a Reconyx® camera painted to blend in with the surrounding rocks, and the third person floated and measured the single egg. Each camera was mounted on a stake embedded in the rocks ideally about 1 to 1.2 m away from the nest, camouflaged with rocks, and aimed at the nest to record incubation shifts and feedings. Camera placement depended on the terrain around the nest. The egg was weighed to the nearest 0.5 g with a 100 g spring scale, measured with digital calipers to the nearest 0.1 mm (length and width), and floated to determine stage of incubation (Fig. 3). Stage of incubation was determined based on an assumed 30-day incubation period (Day et al. 1999) and egg floating benchmarks described by Rizzolo and Schmutz (2007).

Figure 3. Floating a Kittlitz's murrelet egg to determine stage of incubation (above about 25 of 30 days) on Kodiak Island, AK.

In addition to egg measurements, the data keeper recorded a nest identification number (KOD for Kodiak, species alpha code KIMU, last two digits of the year, and number of nest found, e.g. KODKIMU1601 for first nest discovered in 2016). The date, UTM coordinates, time a nest was discovered, time the nest was left, observers, predators observed, confirmation of species, elevation, and the direction the adult flushed were also recorded. Prior to leaving the nest vicinity, researchers deployed a temperature data logger (Thermochron® iButtons, Embedded Data Systems DS1922L-F5#) in a makeshift nest bowl similar to the active nest (i.e. similar nest bowl composition, aspect, and nest rock) constructed within a six meter radius of the active nest. iButtons were programmed to record temperature every 10 minutes in 0.5°C increments and stored 8192 8-bit temperature readings. Each button logged new temperature events for just under 57 days. The iButton was deployed to measure the microclimate at each nest site to better understand the differing thermoregulatory costs of each chick. To encourage the adult to return quickly we attempted to keep time at the nest less than 10 min and moved to a different face of the ridge/peak or to a different ridge post-discovery. Aside from scheduled nest visits we remained at least 50 m from all active KIMU nests during subsequent search efforts and activities in the area.

Using estimates of hatch date based on floating eggs, nest sites were visited at three intervals throughout development to obtain growth measurements. At each visit, observers noted whether the nest was active or inactive, checked camera function, looked for prey remains, recorded the weather, and collected morphological measurements of the chick. If a chick was present it was taken >30 m from the nest site to be processed to avoid disturbance at the nest. Morphological measurements taken included: head length, culmen, tarsus, wing chord from the wrist joint to tip of longest primary without depressing the wing, wing chord with the wing held flat against the ruler, and longest rectrix. Mass was measured with a spring scale to the nearest 0.5 g for chicks weighing <100 g, and to the nearest 2.5 g for chicks heavier than 100 g. Additional chick attributes recorded included percent coverage of down and presence or absence of an egg tooth. Fecal samples were collected at each visit and archived for potential future research. With an average fledging period on Kodiak of 24 days, nest checks were made at 4 to 6 days, 14 to 16 days, and 18 to 21 days to get an adequate representation of growth throughout development. Chicks were banded during the second or third nest check with U.S. Fish and Wildlife stainless steel bands. The second observation period was changed in 2012 from 9–13 days to 14–16 days to obtain growth information for the later period (Corcoran et al. 2014).

Nest Cameras and Estimation of Fish Length

A camera, Reconyx® PC900 or PC90, was placed at each nest discovered (Fig. 4). In 2009 and 2010, Lawonn et al. (2012) investigated the effects of cameras on nest predation by randomly placing cameras at every other active nest discovered. He found no correlation between nest cameras and depredation (n=27); in fact, nests with a camera had a higher rate of fledging (0.21 with cameras vs. 0.10 without cameras). Starting in 2011, a camera was placed at every nest, and in subsequent years (2012-2013) there was a substantial increase in nest success (17% to 46%). Prior to the field season each camera was painted to blend in with the surrounding environment, fitted with a visor to reduce glare and rain on the lens, and tested for operation. Nest cameras were set to trigger on motion and at an interval of 3-min to provide images from discovery to fledging. When the motion sensor was triggered the camera snapped three photographs at 1-s intervals. During the 2011 nesting season, three cameras were set to 1-min intervals, and out of 199 meal deliveries recorded, only one visit was shorter than the 3-min interval, indicating a 3-min interval was adequate to film >99% of visits of parents to the nest (Lawonn et al. 2012).

Figure 4. A Reconyx® camera camouflaged to look like surrounding rock monitoring a Kittlitz's murrelet nest on Kodiak Island, AK.

Camera images from discovery until 24 hours after fledging or nest failure were reviewed at the end of the field season. Incubation shifts, hatching, adult brooding, meal deliveries, depredations, fledging, nest fate, and any other events at the nest were recorded. For each meal delivery, the date, time, prey species, and whether the prey was consumed were inferred to the maximum capability of the images. To the extent possible, the length of each fish was recorded as a ratio to the number of adult head lengths. An adult head length of 57.3 mm (from an adult captured on Kodiak in 2015) was multiplied by each measured ratio to obtain an estimated fish length.

During nest checks, cameras were inspected for battery life, memory space, and performance. Nest fate was determined from camera images and physical evidence present during the final nest check when the camera was retrieved. Predation events were described with date, time, species, and written comments. A nest was considered abandoned if an adult left an unattended egg and never returned. In the case of camera failure, physical evidence at the nest site helped to infer nest fate. A large fecal ring at the back of the nest accompanied by down, shed by the chick just prior to fledge, was taken as evidence of a successful nest. If there was no chick present on the first nest check, hatch was determined by the presence of fecal and egg fragments and a depredation event was assumed.

Nest Site Characteristics

Dedicated nest searching ended in mid-July. The remainder of the field season was spent visiting nests to gather growth rate data, and measuring physical characteristics at each nest site, along with randomly selected sites near nest site locations. Nest site measurements included slope, aspect, elevation, and whether the ocean was in view. Areal extent of cover type was estimated within a 5 m radius, with less detailed estimates within radii of 25 and 50 m. Within the 5 m plot, percent coverage was estimated for bare soil, rock <10 cm diameter, rock 10–30 cm diameter, rock >30 cm diameter (including exposed bedrock), available nest rock (>20 cm diameter), and six categories of vegetation (lichen, orange crustose lichen, moss, grass, forb, and shrub). In the 25 and 50 m plots, the percentage of area that was vegetated and unvegetated was estimated (Lawonn et al. 2012).

In our study area, KIMU laid a single egg in a shallow depression scraped in the rocky substrate, often having a ‘nest rock’ above the scrape that offered some shelter from the elements and helped to hide the incubating adult and later the growing chick. While at the nest site, researchers identified up to three nest rocks and measured the dimensions of the rocks (length × width × height). These rocks were usually directly above the nest scrape but could be off to the side of the nest bowl. The depth and diameter of the nest bowl were measured with a steel ruler to the nearest millimeter. Two plots near the nest site were randomly selected in the field and the same measurements made at nest sites were taken at the random sites for the 5, 25, and 50 m plots, except that the physical data measured at the nest bowl (nest rock dimensions, nest bowl dimensions) were not collected. Prior to leaving each nest, four pictures of the habitat were taken from the two sides of the nest, upslope, and downslope.

Samples were collected during each nest visit from the fecal ring located at the back of the nest, and buried at campsites to keep cool. Upon returning to town these samples were stored in a freezer at the KNWR headquarters. Any prey fish left around the nest site were collected when present. These specimens were buried at camp, frozen at the first chance, and were also placed in a freezer at the KNWR headquarters office upon return to town. Egg shell fragments and adult contour feathers were collected opportunistically, stored in envelopes, and archived for future research at the KNWR headquarters.

Predators Observations

Using protocol described by Sargeant et al. (1993) the number of predators observed during the field season and the number of places a predator species were seen each day were recorded. All observations were within 1 km of ultramafic rock nesting habitat at the four sites.

Results and Discussion

Nest Searching and Monitoring

On 26 May a research team of seven was flown into Duncan Lake on the west side of Kodiak Island. The team spent the summer hiking between four basecamps (Fig. 5) that served as staging points to systematically search for KIMU nests, monitor nests once discovered, and conduct habitat surveys at the end of the field season. After 74 days in the study area the crew flew back to the city of Kodiak on 7 Aug. Dedicated nest searching occurred from 29 May to the 21 July. From 2008-2015 the research team consisted of three to four people, and each of the four study sites was searched once before any site was searched a second time. However in 2016 the crew increased to five to seven people, split into two separate teams. Nest searching two sites simultaneously allowed us to search each of the four sites twice and one site a third time. It was hoped that by increasing the amount of search effort we would discover more nests, particularly if many nests were failing shortly after initiation and might be missed by large intervals between nest searches.

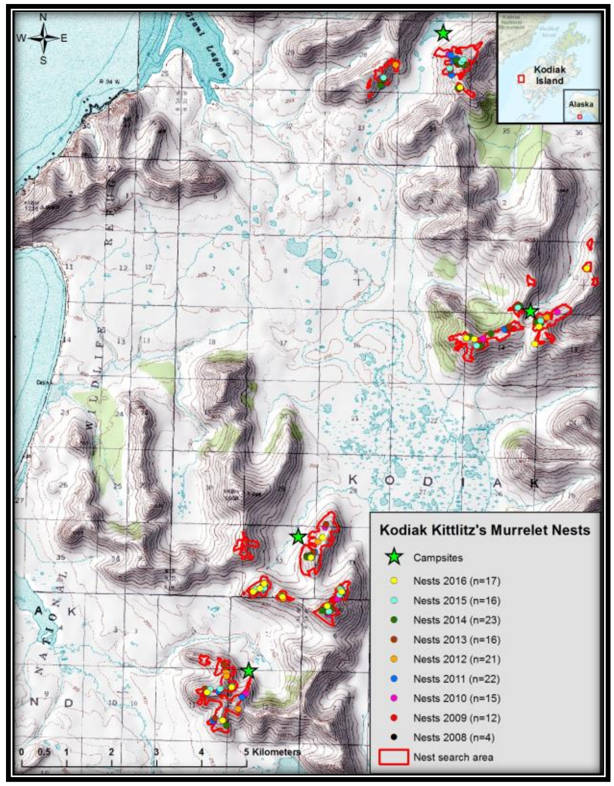

Figure 5. Kittlitz's murrelet nest locations from 2008-2016 on Kodiak Island, AK.

Throughout the study, search effort depended on a variety of factors including the number of volunteers and field season duration, and variable seasonal constraints such as weather and time devoted to nest monitoring, which was much higher in years when many nests hatched. While the ultramafic rock study sites that were searched each year remained the same, the total area covered each season by nest searchers changed due to the variable time available for repeated searches. For years with full GPS records of transects during all search efforts (2009, 2013-2016) we determined the total area searched (not including repeated searches) and search effort (including the repeated searches). As expected with a larger field crew in 2016 both the total area searched (3.15 km²) and search effort (5.06 km²) were above the averages across all years of the study (2.32 and 3.53 km² respectively). There was no correlation between either area searched or search effort and nest density. During the last two field seasons of the study both the area searched and search effort increased over previous years, however, nest density was lowest (see Appendix B).

It has been assumed that KIMU, like other seabirds, probably do not breed every year (Day et al. 1999), and one direct measurement of breeding propensity for the species was only 20% of 191 birds radio-tagged in Icy Bay initiated nesting over a six year period, 2007-2012 (Kissling et al. 2016). In Icy Bay the decision to breed and the timing of nest initiation by KIMU was related to factors reflecting spring phytoplankton blooms. Locating fewer KIMU nests on Kodiak in years when more effort was expended in nest searching implies lower breeding propensity in those years.

In 2016, search efforts yielded 17 active KIMU nests discovered in egg stage, 14 of these were found after flushing an incubating adult from the nest. The other three nests were discovered during systematic searching when an adult was spotted incubating among the rocks. The average distance at which an adult KIMU flushed from the nest in response to searchers was 3.3 m in 2016. The range of flush distance in 2016 (0.3-8.0 m) was similar to previous years of the study. On one occasion researchers came within 0.5 m of an incubating adult before spotting it on the ground. They were able to back away and place a camera 3 m from the nest without flushing the adult. A live chick in a nest was discovered without an adult flushing on three occasions in 2013, but no nests were found in this manner since.

In 2016, 15 nests were discovered within 20 m of nest sites found in previous years of the study, and four of these were in nest bowls used in previous years. Across all seasons, 2008-2016, we documented reuse of the same nest bowl in different years on 15 occasions (Appendix C). The two closest nests active simultaneously in 2016 were 144 m apart. Three pairs of nests were each active within 200 m of each other. In previous years, active nests have been as close as 12 m apart. In total, 54 nests have been located within 20 m of at least one other nest discovered in the same or preceding year.

As in previous years there was a wide range of return times for adults after initial flush (14-1059 min) (Appendix D). The mean return time for 2016 was 402 min, which is among the longest recorded for the nine year study (Table 1). Average time from initial flush to when researchers left the nest was 11 min in 2016, slightly higher than the 10 min goal. On one occasion we spotted a returning murrelet fly by the nesting area while we were at the nest, indicating KIMU will return to the nest within six minutes of initial flush.

Table 1. Summary of Kittlitz's murrelet adult return times after the initial flush of an incubating adult on Kodiak Island, AK, during the 2009-2016 nesting seasons.

Year	Mean Return Time	Minimum Return Time	Maximum Return Time
2009	174	15	455
2010	156	17	583
2011	370	14	1329
2012	487	17	776
2013	210	23	540
2014	359	15	1025
2015	334	20	753
2016	402	14	1059
Mean	311	16	815

*The outliers of 2135 min in 2012 and the 3404 min in 2015 were removed from the analysis.

From 2009-2016, we documented adult attentiveness during incubation and timing of incubation switches. Observations revealed 95% of incubation switches occurred between 03:00 and 06:00 (Appendix E). Sunrise on Kodiak Island occurred between 05:00 and 07:00 during the monitored breeding seasons. Switching incubation duties in low light conditions is likely a measure to avoid detection by predators.

For nests with greater than three days of camera monitoring during incubation, we calculated adult nest attendance rate as the proportion of time one or both adults were present at the nest during egg stage. On average, adult KIMU during the 2016 field season were more attentive to their nests (98.8%) than the mean over the nine-year study (95.9%)

Table 2. Kittlitz's murrelet nest initiation dates on Kodiak Island, AK, from 2008-2016. Average initiation dates include known and estimated hatch back calculated based on a 30-day incubation period.

Year	Average Initiation Estimates
2008	22 June
2009	3 June
2010	11 June
2011	6 June
2012	14 June
2013	15 June
2014	4 June
2015	11 June
2016	7 Jun

(Appendix F).

Based on estimated and known hatch dates the average initiation date in 2016 was 7 June (range 18 May to 4 July) (Table 2). Renesting has likely been observed in multiple seasons (2008 and 2010-2016) represented by birds initiating nests as late as 15 July well beyond mean initiation dates recorded for this species on Kodiak Island. Tendency to re-nest following initial nest failure has been frequently reported for the congeneric marbled murrelet (*Brachyramphus marmoratus*) (Nelson et al. 2010).

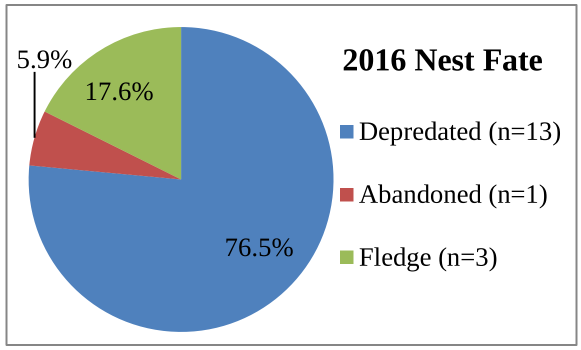

Figure 6. Kittlitz's murrelet 2016 nest fates on Kodiak Island, AK.

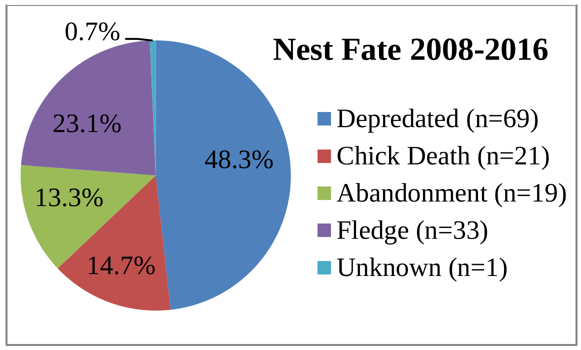

Figure 7. Compiled Kittlitz's murrelet nest fate from 2008-2016 on Kodiak Island, AK.

Nest Success

Apparent nest success was 18% (3 of 17) (Fig. 6). Of the 17 nests, 13 nests were depredated by red fox (nine at the egg stage and four at chick stage), three chicks fledged, and one egg was abandoned after at least 32 days of incubation (Table 3). The fate at each nest could be determined by camera images and was supported by physical evidence at the nest. Detailed nest fates for 2016 can be found in Appendix G and a summary of nest fates from 2008-2016 can be found in Appendix H, Table 4, Figure 7, and Figure 8.

Table 3. Summary of Kittlitz's murrelet nest fates on Kodiak Island, AK, during the 2016 nesting season.

Nest Fate	Number of nests
Egg abandoned	1
Failed during incubation, red fox depredation	9
Failed during nestling stage, red fox depredation	4
Failed during nestling stage, dead chick found on nest scrape	0
Fledged young	3
Total	17

Table 4. Fate of Kittlitz's murrelet nests found on Kodiak Island, AK, during 2008-2016.

Nest Fate	2008	2009	2010	2011	2012	2013	2014	2015	2016	2008-2016
Depredated	2	8	7	9	4	6	12	8	13	69
Dead chick	0	1	2	8	3	1	5	1	0	21
Abandoned	2	2	2	1	4	1	2	4	1	19
Fledge	0	1	4	4	9	8	4	0	3	33
Unknown	0	0	0	0	1	0	0	0	0	1
Trapped	0	0	0	0	0	0	0	3	0	3
Total	4	12	15	22	21	16	23	16	17	146

Similar to previous years when predation rates were high, red fox (*Vulpes vulpes*) predation was the major cause of nest failures (n=13, 77%) and the highest recorded during this study. Predation rates dropped from 49% in 2008-2011 to 26% in 2012-2013, and coincided with an increase in nest success during the same time period. In 2014, 2015, and 2016 predation rates increased to 52%, 62%, and 77% respectively, three of the four highest recorded during this study (Appendix I).

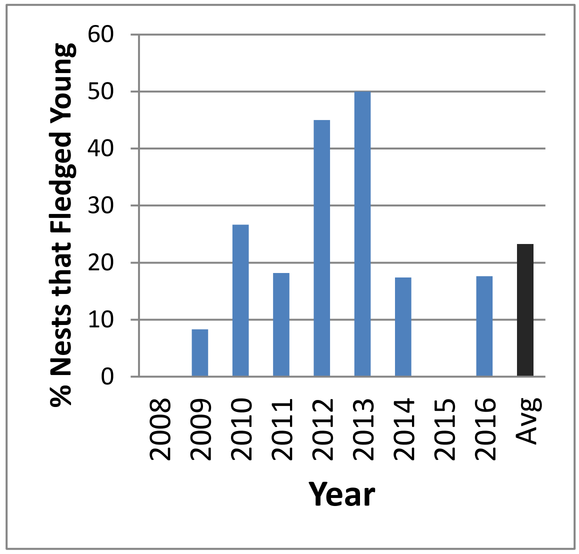

Figure 8. Annual percentage of Kittlitz's murrelet nests that fledged on Kodiak Island, AK, from 2008-2016.

Across all years of the study the predator responsible for nest depredation was recorded by camera at 44 of 69 nests that failed due to predation. Of those 44 identified predators, 41 were red fox (Fig. 9). More depredation events occurred during incubation (50) than during chick rearing (19). Red fox were the only species documented depredating KIMU nests on Kodiak Island with the exception of 2014 when black-billed magpies (*Pica hudsonia*) depredated three nests at egg stage.

Figure 9. Red foxes captured on camera depredating Kittlitz's murrelet nests during the 2016 field season on Kodiak Island, AK.

We did not have any chicks die on the nest for unexplained reasons in 2016, but this has been a frequent cause of nest failure (n=22, 15%) throughout the study (Appendix K). From 2011-2012 seven chick deaths were attributed to saxitoxin, a neurotoxin produced by some species of marine dinoflagellates (Shearn-Bochsler et al. 2014). Additional chick deaths occurred in 2013 and 2014, and the circumstances surrounding the single chick death in 2013 and four of the five deaths in 2014 were similar to the deaths attributed to saxitoxin in 2011-2012. In all cases an apparently healthy chick on the nest died less than six hours after being fed a Pacific sand lance (*Ammodytes hexapterus*). Two of the four chicks that died on the nest in 2014 were sent to the National Wildlife Health Center (NWHC, Madison, WI) for necropsy and both tested positive for saxitoxin (NWHC Case no. 24910). In both cases stomach contents and liver tested positive and for one chick levels were high enough (338.05 ng/g in stomach contents, 104.73 ng/g in liver) to identify saxitoxin poisoning as the probable cause of death. Given that few of the chicks could be salvaged (n=16) and fewer tested (n=10) these cases represent a minimum estimate, and deaths across multiple years indicate that saxitoxin poisoning is potentially an important chronic factor contributing to KIMU chick mortality.

Predator Observations

The length of time spent in the field each season ranged from 61-91 days. We recorded the species of predator seen each day. When the crew was split into multiple groups working in different locations predator observations were recorded separately, increasing the number of observation days. We calculated the total number of days a predator species was seen during a field season and divided that by the total observation days that year. This percent of observation days a predator species is seen is the only metric for predator abundance from year to year (Table. 5).

Table 5: Summary of data used to calculate % of observation days predators were seen while conducting Kittlitz's murrelet nesting ecology research on Kodiak Island, AK, from 2009-2016.

Year	Filed Arrival	Field Departure	Field Days	Observation Days*	% of Observation Days a Red Fox was Seen
2009	26-May	3-Aug	69	69	26.1%
2010	26-May	23-Aug	89	89	24.7%
2011	27-May	26-Aug	91	91	12.1%
2012	1-Jun	3-Aug	63	61	13.1%
2013	4-Jun	4-Aug	61	65	6.2%
2014	24-May	8-Aug	76	81	23.5%
2015	23-May	10-Aug	79	96	20.8%
2016	26-May	7-Aug	73	129	14.0%

*Observation days includes when the crew was split up in multiple groups in different locations recording predators separately.

Black-billed magpie and bald eagle (*Haliaeetus leucocephalus*) have been the most frequently observed predators in recent years. While only red foxes and black-billed magpies have been documented depredating KIMU nests on Kodiak Island, additional potential predator species frequently observed included common raven (*Corvus corax*) and golden eagle (*Aquila chrysaetos*). For more information on predator observations refer to Appendix J.

In general fewer red fox were observed in years when depredation rates were low (2012-2013) (Appendix J). The decline in predation rates during the 2012-2013 nesting season could have resulted from fewer fox in the nesting habitat due to the abundance of other prey items such as ptarmigan, snowshoe hare, and tundra voles available in more vegetated habitats at lower elevations. We have speculated that the magnitude of predator influence may be related to predator composition, abundance, and availability of alternative prey in habitats used for nesting by KIMU (Lawonn et al. 2012). However, additional resources beyond the scope of the current research would be necessary to determine what influences these factors have on predation rates.

Nest Site Characteristics

Nest characteristics in 2016 were consistent with observations collected during the previous eight years of research. All nests discovered during this study where located in ultramafic rock habitat with less than 35% vegetation coverage within a 5 m radius. In 2016 no nest exceeded 12% vegetation coverage within a 5 m radius. Nests consisted of a shallow nest bowl made of loose rocks 1-50 mm in diameter downslope from a large rock (commonly known as a nest rock).

The average percent of vegetation coverage was within 5% of eight year means for coverage. Nests have been found at a range of elevations from 162 m to 455 m. The 2016 mean nesting elevation (323 m) was close to the average across all nine years (322 m), and nests in 2016 were found on similar slopes (mean 33°, range 23-42°) to the average for all years(mean 32°; range 20-49°). Additional information on nest site characteristics can be found in Appendix L.

In 2016 we estimated ground coverage at 200 random and 34 near nest habitat plots. Data have been collected on about 1400 random plots within the search area from 2008-2016. Analysis of nest site habitat characteristics from 2008-2011 indicated that KIMU selected sites with lower vegetation cover, more rocks 5–30 cm, fewer rocks >30 cm, and steeper slopes than random sites. However, there was no observed relationship between the habitat covariates and nest survival rate (Lawonn 2012). We intend to continue the analysis to determine if increased sample size will identify any new significant relationships between nest survival and habitat characteristics.

Meal Delivery and Chick Growth

Annually from 2009-2016, we calculated the time between every other prey delivery (presumably the time between prey deliveries by the same adult) to determine the shortest duration between deliveries by the same adult. We then used average flights speeds recorded for the similar marbled murrelet (83 km/hr) during radar studies on Kodiak Island (Cragg et al. 2016) to determine the farthest possible distance an adult KIMU could travel during the shortest time between deliveries (Appendix M). Possible foraging locations associated with shortest time between deliveries indicate that at times KIMU forage close to the study site (<8 km) (Fig. 10).

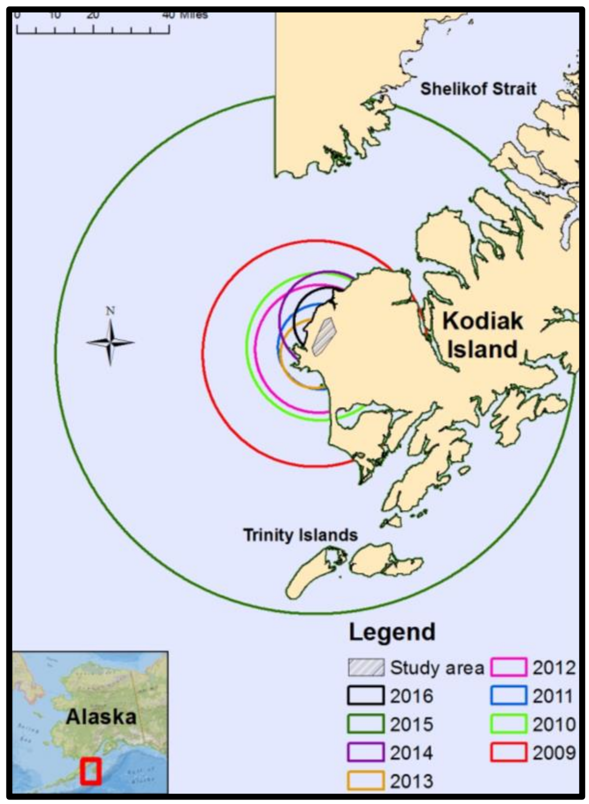

Figure 10. Estimates using the shortest duration between nest visits by adults to provision chicks to calculate minimum foraging area of breeding KIMU by year on Kodiak, AK, from 2009-2016. Estimates were based on a single nest each season representing the shortest interval between every other prey delivery, and average flight speeds for marbled murrelets during radar studies on Kodiak Island, AK (Cragg et al. 2016).

Timing of meal deliveries varied across individual nests and years. However, adult KIMU delivered prey to chicks most frequently between the hours of 05:00-08:00 and 22:00-01:00 (Appendix N).

Of the 17 active nests discovered in 2016 seven produced a chick. Over the course of the field season we observed adults returning with a fish at all of the nests that reached chick stage, however, one of the seven nests failed before receiving a prey delivery. Nonetheless, adults attempted three fish deliveries after the chick was depredated by a red fox.

While nests were active, cameras recorded 408 fish delivered to chicks at an average of 4.1 fish deliveries per day (Table 6) in 2016. During the first three days after hatch, the average fish delivered per day, number of deliveries, and the length of fish were among the lowest compared to all years of the study (Table 7). Combing data across years delivery frequency and fish size increase after the first few days post-hatch (Appendix O). Of the identified prey deliveries in 2016 Pacific sand lance was the most abundant fish species delivered to chicks comprising 61.1% followed by capelin at 38.6%. This was the highest percentage of capelin delivered to chicks during a nesting season that we have observed during this study (Fig. 11). We have observed variation among and within seasons in the number of deliveries consumed during the prefledge period, the duration of the prefledge period, and the sum of fish lengths delivered during the prefledge period (Table 8, Appendix Q).

Table 6. Annual meal delivery summary for Kittlitz's murrelet chicks on Kodiak Island, AK, between hatch and nest success or failure from 2009-2016. Sample size (n) represents number of chicks that received at least one prey delivery and were observed for a full day.

Year	n	Mean meals /day	Observed fish deliveries	Average fish length (mm)*	Average time between deliveries (hr:min)	Total days monitored post-hatch
2009	2	3.5	117	132.6	5:51	33
2010	5	3.6	173	133.9	5:52	48
2011	13	4.7	984	136.9	4:41	213
2012	12	4.0	729	134.3	5:21	186
2013	10	3.8	701	130.4	5:58	190
2014	8	3.7	310	123.8	5:43	88
2015	3	1.9	18	111.2	8:58	10
2016	6	4.1	408	113.8	5:41	104

*Each fish to adult head ratio obtained from nest images was multiplied by 57.3 mm (assumed adult head length) to obtain an estimated fish length.

Table 7. Annual meal delivery summary from hatch (day 0) to day 3 for Kittlitz's murrelet chicks on Kodiak Island, AK, from 2009-2016. Sample size (n) represents the number of chicks observed continuously from day 0-3.

Year	n	Average deliveries a day from day 0-3	Average sum of deliveries from day 0-3	Average fish length day 0-3 (mm)*	Average sum of fish length from day 0-3 (mm)*
2009	2	1.63	6.50	128.70	836.58
2010	2	2.58	12.50	120.62	1495.44
2011	10	3.00	12.40	126.80	1576.15
2012	8	2.53	10.13	120.43	1219.34
2013	6	3.08	12.33	115.35	1422.66
2014	4	2.25	10.25	111.18	1131.65
2015	1	1.92	9.00	110.71	1053.17
2016	2	2.25	9.00	105.69	915.63

*Each fish to adult head ratio obtained from nest images was multiplied by 57.3 mm (assumed adult head length) to obtain an estimated fish length.

Growth rate, feeding rate, and the length of the prefledge period (hatch to fledge) will be analyzed to determine how these factors interact to influence nest success. For example, variation in prey deliveries may impact growth rates therefore extending or shortening the pre-fledgling period in turn changing the length of exposure to predation. We collected growth measurements on five chicks during 14 nest visits. Data on prey deliveries to chicks in each season will be used to develop models evaluating whether variations in the energy content of prey fish could explain poor reproductive performance in this sensitive species (Appendix P, Appendix Q).

Table 8. Frequency of meals (single fish) delivered to Kittlitz's murrelet chicks on Kodiak Island, AK, in 2016. A total of 408 deliveries were recorded while a live chick was present. Total days monitored post-hatch starts at hatch (day 0).

Nest #	Mean meals a day	Range of meals a day	Total fish delivered while active	Total days monitored post-hatch	Mean fish length (mm)	Sum of fish length (mm)	Nest Fate
1601*	4.9	2-7	55	13	98.0		Depredated ~17 days post-hatch
1605	2.0	1-3	4	2	104.0		Depredated 1 day post-hatch
1606**	4.1	1-6	65	18	124.7	8,105	Fledged 21 days post-hatch
1610***	3.3	0-6	66	21	130.8		Depredated ~20 days post-hatch
1611	3.0	0-5	75	26	119.3	8,944	Fledged 25 days post-hatch
1613	4.9	0-10	143	29	104.5	14,946	Fledged 28 days post-hatch

*Nest camera did not work until 5 days post-hatch.
**Nest camera did not work until 4 days post-hatch.
*** Nest camera only recorded motion-triggered photographs until 17 days post-hatch. Both 3-min interval and motion -triggered photos were recorded after day 17.

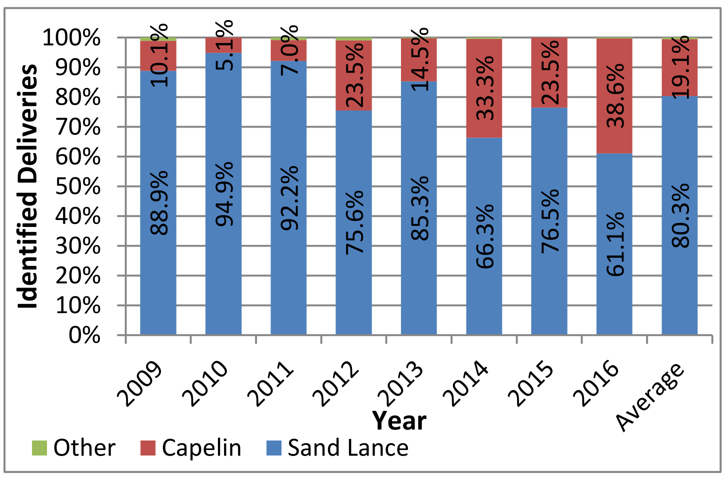

Figure 11. Annual percentages of fish species fed to Kittlitz's murrelet chicks on Kodiak Island, AK, from 2009-2016.

Figure 12. Kittlitz's murrelet chick, KODKIMU1610, banded during the third nest visit in 2016 on Kodiak Island, AK.

We banded four KIMU chicks during the second or third nest visit with U.S. Fish and Wildlife Service stainless steel bands (Fig. 12). Three of the four fledged. The youngest chick banded was 13 days old. The oldest was 20 days old, had only 5% of its down, and fledged 12 hours later.

Cameras did not capture interval photos at all nests during the 2016 field season due to camera card formatting malfunction. At seven nests, only motion triggered photos revealed nest events prior to the first nest visit by researchers when the cameras were replaced (only three nests were still active). One nest camera failed completely after initial setup, but the chick was present during the first nest visit and a working camera was installed. The distance of the camera to the nest was dictated by terrain and the need to obtain clear images of prey deliveries to chicks (Fig. 13). However, based on observations from multiple field seasons cameras set on a motion sensor should not be put closer than 0.8 meter, with an optimal distance of 1-1.5 meters. Cameras at nests differed in the sensitivity at which they would trigger (product of individual camera function or placement) and could not be depended on to capture all nest activities.

Figure 13. Reconyx® images of Kittlitz's murrelet adults delivering Pacific sand lance (left) and capelin (right) to a chick waiting in a nest on Kodiak Island, AK, during the 2016 field season.

Conclusion

Despite a larger crew and increased search effort in 2016 we found fewer KIMU nests than on average based on previous seasons. This result likely reflected that fewer birds initiated nests in 2016 since this species does show low breeding propensity in other regions (Kissling et al. 2016). Low nest initiation by KIMU on Kodiak in 2016 may have resulted from unusual conditions in marine ecosystems throughout the Gulf of Alaska (GOA) from 2014-2016.

In 2014, large concentrations of exceptionally warm water in the GOA and off Baja California coalesced forming what has been labeled "the blob" (Bond et al. 2015) and between the winters of 2014 and 2015 the northeast Pacific experienced the largest marine heatwave ever recorded (Di Lorenzo and Mantua 2016). Record-setting sea surface temperatures were as much as 3°C higher than average in the GOA and corresponded with the lowest KIMU nest survival documented to date on Kodiak in 2015. Only 16 KIMU nests were located in 2015, abandonment rates were higher than any previous season, only three nests hatched, and none successfully fledged young. During 2015 seabird productivity in the GOA was below average for almost all common species, black-legged kittiwakes (*Rissa tridactyla*) exhibited widespread breeding failures (Dragoo et al. 2016), and colony abandonment was recorded for common murres, the first time such abandonment has occurred in over 35 years of monitoring. In March 2015 a seabird die-off began in the GOA which continued into spring 2016. The temporal and spatial scale of the die-off was unprecedented as were the number of dead birds, estimated to be in the hundred thousands, primarily common murres. Carcasses from several locations in the GOA were necropsied and the cause of death in all cases was starvation, leading researchers to hypothesize that the die-off was related to changes in the abundance or distribution of forage fish preferred by seabirds in response to the record warm sea surface temperatures (USFWS 2016). Evidence strongly points to food stress negatively impacting seabird fecundity, survival, chick growth, assimilation efficiency, and cognitive abilities later in life (Brekke and Gabrielsen 1994, Kitaysky et al. 2003, Kitaysky et al. 2006, Kitaysky et al. 2010).

Due to their reliance on cold water habitats throughout their life cycle, it has been proposed that KIMU are a leading indicator species of ecological change in response to climate warming across marine ecosystems in Alaska (Piatt 2014). This species prefers glaciated coastal areas for nesting and migrates to the Bering, Chukchi, and Beaufort seas after breeding before moving to wintering areas in polynyas or along the sea-ice edge of the Bering Sea. The low number of nests and low nest success on Kodiak in 2015-2016, appears to support the view that KIMU are a very sensitive indicator of annual variation in marine ecosystems. Decrease in fish availability starting in 1989 and lasting through at least 2000 coincided with a decline in KIMU populations of about 30% per year. From 2005-2012, data from three KIMU nesting studies, including Kodiak Island, Agattu Island, and Icy Bay, indicated that only 26% of nests successfully fledged young (Felis et al. 2016). It has also been proposed that if annual survival of adult murrelets is 86-90% then nest success needs to be from 23-39% for populations to remain stable (Day and Nigro 2004). However, recent research estimated annual survival of adult KIMU at only 80% (Kissling et al. 2015), indicating that low overall nest success at sites currently studied may be inadequate to sustain populations.

Data from this research project will continue to be analyzed in cooperation with SIU, Western Ecosystems Technology Inc., U.S. Geological Survey, and co-operators investigating KIMU chick death attributed to saxitoxin. Our goal is to determine the influence of diet composition on nest success. Research will assess the hypothesis that the KIMU population has declined in part due to lower chick growth rates resulting from reduced availability of high-energy forage fish. This research will offer insights into broader issues such as the ‘Junk Food Hypothesis’ and effects of oceanic regime shifts on population trends. These factors, mediated by climate change, might have been primary contributors to declines seen across a wide geographic range not only for KIMU but for other marine predators including black-legged kittiwake and Steller sea lion (*Eumetopias jubatus*).

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APPENDIX A. Weather conditions, Kodiak Island, AK, 2008-2016 (NOAA 2016).

Year	Site	Dates	Average Daily Mean Temp (˚C)	Average Daily Max Temp (˚C)	Average Daily Min Temp (˚C)
2008	Booth Lake	14 Jun – 31 Aug	10.8	14.0	7.7
2009	Booth Lake	1 Jun – 31 Aug	10.4	13.4	7.2
2010	Booth Lake	1 Jun – 31 Aug	10.5	12.9	8.0
2011	Booth Lake	1 Jun – 31 Aug	10.1	13.0	7.4
2012	Booth Lake	1 Jun – 31 Aug	10.1	13.3	6.8
2014	Booth Lake	1 Jun – 31 Aug	11.7	15.2	7.7
2015	Booth Lake	1 Jun – 31 Aug	11.9	15.0	8.5

*2013 Data from Booth Lake is unavailable due to equipment malfunction and 2016 data was unavailable during the time of this writing.

Year	Site	Dates	Average Daily Mean Temp (˚C)	Average Daily Max Temp (˚C)	Average Daily Min Temp (˚C)	Total Rainfall (cm)	Average Daily Rainfall (cm)
2008	Kodiak Airport	1 Jun - 31 Aug	10.7	13.7	7.8	65.3	0.71
2009	Kodiak Airport	1 Jun - 31 Aug	11.6	15.0	8.3	42.7	0.46
2010	Kodiak Airport	1 Jun - 31 Aug	11.4	14.1	8.7	33.8	0.37
2011	Kodiak Airport	1 Jun - 31 Aug	11.7	14.5	8.9	32.0	0.35
2012	Kodiak Airport	1 Jun - 31 Aug	11.2	14.2	8.1	20.4	0.22
2013	Kodiak Airport	1 Jun - 31 Aug	13.2	16.7	10.0	36.8	0.40
2014	Kodiak Airport	1 Jun – 31 Aug	12.7	15.9	9.4	39.9	0.43
2015	Kodiak Airport	1 Jun – 31 Aug	13.8	17.2	10.4	21.4	0.23
2016	Kodiak Airport	1 Jun – 31 Aug	14.1	17.4	11.0	23.4	0.25
Mean			12.26	15.40	9.18	35.07	0.38
Standard Deviation			1.147	1.340	1.030	13.106	0.142

APPENDIX B. Summary of search area and Kittlitz's murrelet nest density on Kodiak Island, AK, during the 2009-2016 nesting seasons.

Year*	Area Searched** (km^2)	Search Effort*** (km^2)	Nest Density (number of nests/area searched)
2009	1.64	2.49	7.33
2013	2.09	2.27	7.64
2014	2.78	3.52	8.27
2015	2.96	4.33	5.41
2016	3.15	5.06	5.39
Mean	2.32	3.53	6.81

*Complete GPS transects were not available for 2008, 2010-2012.
**Area searched is the total area searched during the field season not including repeated searches of the same site.
***Search effort is the sum of all area covered including repeated searches of the same sites.

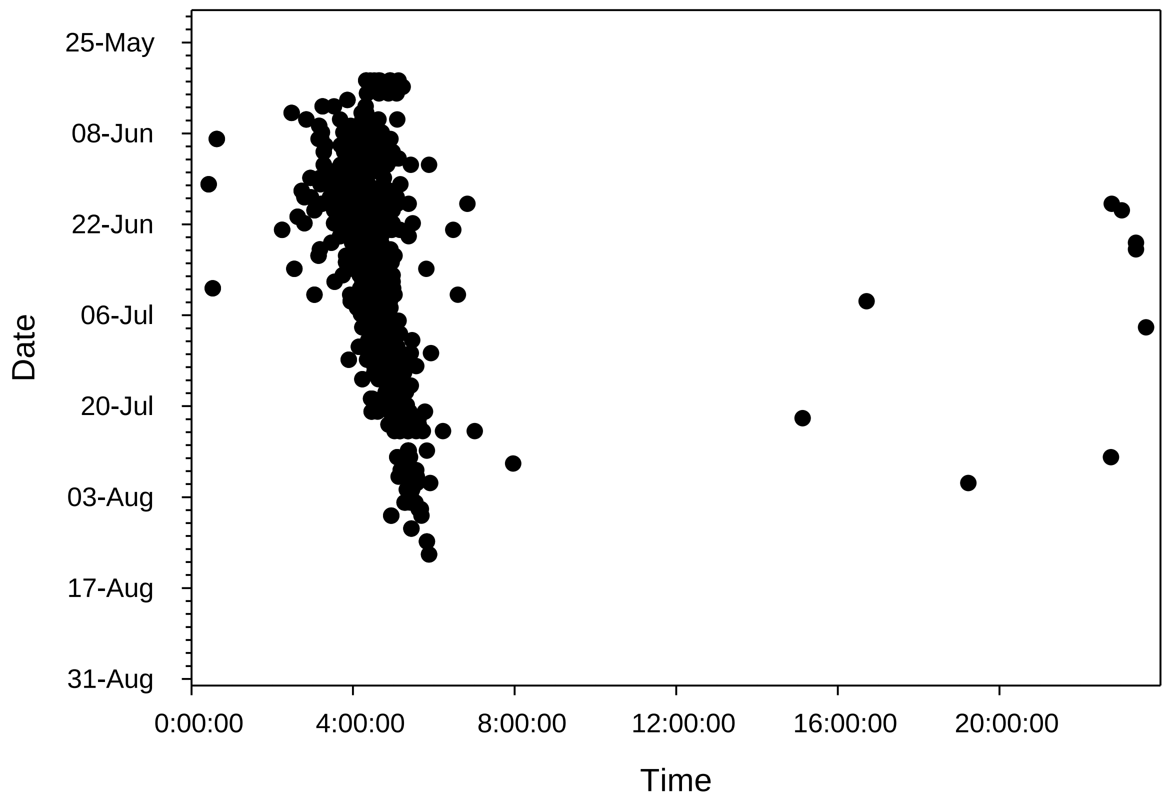
APPENDIX C. Photographs of Kittlitz's murrelet nest sites used in multiple years on Kodiak Island, AK, from 2008-2016: A) KODKIMU1310, a) KODKIMU1605, B) KODKIMU1016, b) KODKIMU1113, C) KODKIMU0801, c) KODKIMU1118.

APPENDIX D. Adult return time after initial flush, age at discovery, flush distance, and egg measurements for Kittlitz's murrelet nests on Kodiak Island, AK, in 2016. Bolded numbers identify nests where known hatch dates obtained from nest cameras were used to determine age of nest at discovery. For all other nests eggs were floated to estimate nest age at discovery.

Nest ID	Return Time (min)	Approximate Age at Discovery (Days)	Flush Distance (m)	Egg Mass (g)	Width (mm)	Length (mm)
KODKIMU1601	~	0	2.5	47	38.9	60.4
KODKIMU1602	14	17	2	45	39.1	56.8
KODKIMU1603	452	20	1	46	39	60.1
KODKIMU1604	294	19	5	45	38.3	58.1
KODKIMU1605	616	**20**	2.5	39	37.5	55.9
KODKIMU1606	~	10	3.5	43	38.6	57.1
KODKIMU1607	854	16	1	44	38.2	69.7
KODKIMU1608	~	18	0.3	34	37.4	57.3
KODKIMU1609	654	17	1	46	38.9	59.5
KODKIMU1610	~	28	1	35	37.4	54.8
KODKIMU1611	85	**25**	4.5	37	36.1	59.4
KODKIMU1612	40	**0**	6	46	36.5	61.7
KODKIMU1612*	368	**25**	5	~	~	~
KODKIMU1613	35	**13**	2	41	37.9	56.6
KODKIMU1614	1059	0	8	55.5	37.8	60.1
KODKIMU1615	1035	11	2	38	35.8	57.3
KODKIMU1616	32	20	3.5	40.5	37.4	58
KODKIMU1617	95	17	8	47	39.3	60.8
Mean	402.4	15.3	3.3	42.9	37.9	59.0
Standard Deviation	383.2	8.4	2.4	5.3	1.1	3.3

*KODKIMU1612 was flushed a second time to replace a camera card after it malfunctioned.

APPENDIX E. Timing of adult Kittlitz's murrelet incubation exchanges (n=554) at 80 camera monitored nests during the 2009-2016 nesting seasons on Kodiak Island, AK.



APPENDIX F. Summary of adult Kittlitz's murrelet nest attendance rate (percent of time one or both adults were present and incubating at the nest) on Kodiak, AK, from 2009-2016. Only nests with greater than three days of consistent camera images were used in analysis.

Year	n	Mean Attentiveness (%)	Min Attentiveness (%)	Max Attentiveness (%)
2009	6	96.8	85.4	100.0
2010	6	98.7	96.8	100.0
2011	14	98.8	93.7	100.0
2012	12	99.5	95.9	100.0
2013	6	95.4	76.8	100.0
2014	14	96.9	71.9	100.0
2015	10	82.0	35.3	100.0
2016	8	98.8	94.9	100.0
Mean	9.5	95.9	81.3	100.0

APPENDIX G. Chronology and fate of Kittlitz's murrelet nests discovered in 2016 on Kodiak Island, AK.

Nest ID	Date Discovered	Approximate Date Initiated*	Hatch Date**	Last Date Known Active	Fate
KODKIMU1601	31-May	31-May	30-Jun	17-Jul	Chick depredated by red fox on July 17th at 00:18
KODKIMU1602	6-Jun	20-May	~	11-Jun	Egg depredated by red fox on June 11th at 03:54
KODKIMU1603	7-Jun	18-May	~	9-Jun	Egg depredated by red fox on June 9th at 19:58
KODKIMU1604	7-Jun	19-May	~	10-Jun	Egg depredated by red fox on June 10th at 02:47
KODKIMU1605	8-Jun	21-May	**20-Jun**	21-Jun	Chick depredated by red fox on June 21st at 09:54
KODKIMU1606	9-Jun	30-May	29-Jun	20-Jul	Fledged July 20th 00:00
KODKIMU1607	12-Jun	27-May	~	21-Jun	Egg depredated by red fox on June 21st at 09:38
KODKIMU1608	14-Jun	27-May	~	17-Jun	Egg depredated by red fox on June 17th at 18:28
KODKIMU1609	16-Jun	30-May	~	17-Jun	Egg depredated by red fox on June 17th at 20:22
KODKIMU1610	16-Jun	21-May	20-Jun	10-Jul	Chick depredated by red fox on July 10th at 02:30
KODKIMU1611	18-Jun	28-May	**27-Jun**	22-Jul	Fledged July 22nd at 04:54
KODKIMU1612	18-Jun	19-Jun	**19-Jul**	19-Jul	Chick depredated by red fox on July 19th at 23:39
KODKIMU1613	3-Jul	20-Jun	**20-Jul**	17-Aug	Fledged 17 Aug at 22:29
KODKIMU1614	4-Jul	4-Jul	~	5-Aug	Egg abandoned on 5 Aug after sporadic incubation by adults
KODKIMU1615	8-Jul	2-Jul	~	14-Jul	Egg depredated by red fox on July 14th at 11:03
KODKIMU1616	13-Jul	23-Jun	~	16-Jul	Egg depredated by red fox on July 16th at 03:03
KODKIMU1617	18-Jul	1-Jul	~	24-Jul	Egg depredated by red fox on July 24th at 23:20

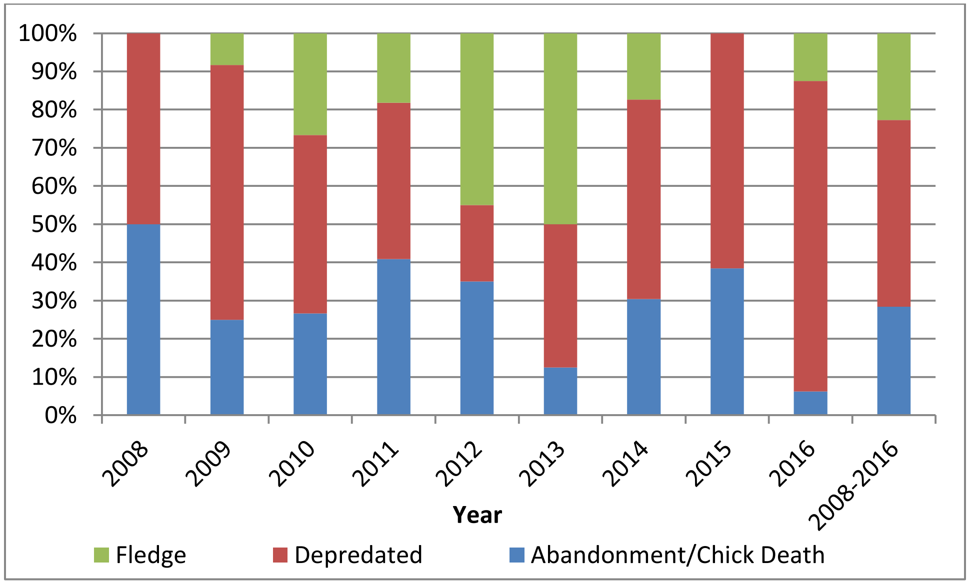
*Estimates based on a presumed 30-day incubation period (Kaler et al. 2008). Age estimated by egg floatation in water (Rizzolo and Schmutz 2007, Kaler et al. 2008), and back calculated from hatch documented by camera images, when possible.
**Bold dates under hatch indicated that hatch was recorded by camera images.

APPENDIX H. Nest fates of active Kittlitz's murrelet nests monitored on Kodiak Island, AK, from 2008-2016.

Nest Fate	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	% Total
Egg abandoned	2	2	2	1	4	1	2	4	1	19	13
Failed during incubation, red fox depredation	0	2	0	5	2	1	5	4	9	28	19
Failed during incubation black-billed magpie depredation	0	0	0	0	0	0	3	0	0	3	2
Failed during incubation, depredation by unknown predator	2	3	3	2	1	3	3	2	0	19	13
Failed during nestling stage, red fox depredation	0	1	1	1	1	2	1	2	4	13	9
Failed during nestling stage, unknown predator	0	2	3	1	0	0	0	0	0	6	4
Failed during nestling stage, dead chick found on nest scrape	0	1	2	8	3	1	5	1	0	21	14
Trapped during incubation (nest failure from abandonment)*	~	~	~	~	~	~	~	3	~	3	2
Unknown	0	0	0	0	1	0	0	0	0	1	1
Fledged young	0	1	4	4	9	8	4	0	3	33	23
Total	4	12	15	22	21	16	23	16	17	146	

*2015 was the only year trapping occurred.

APPENDIX I. Annual summary of fates of Kittlitz's murrelet nests found on Kodiak Island, AK, from 2008-2016.



APPENDIX J. Potential Kittlitz's murrelet predator species observed within 1 km of study areas, Kodiak Island, AK from 2009-2016.

	Species	Date first observed	Date last observed	Total observation days seen	% of observation days seen*
Common name	Scientific name	**2009**			
Eagle spp.	*H. leucocephalus, A. chrysaetos*	26-May	3-Aug	45	65.2%
Rough-legged Hawk	*Buteo lagopus*	29-Jun	13-Jul	2	2.9%
Merlin	*Falco columbarius*	24-Jul	24-Jul	1	1.4%
Parasitic Jaeger	*Stercorarius parasiticus*	13-Jun	7-Jul	6	8.7%
Black-billed Magpie	*Pica hudsonia*	29-May	3-Aug	47	68.1%
Common Raven	*Corvus corax*	16-Jun	3-Aug	15	21.7%
Northern Shrike	*Lanius excubitor*	6-Jun	18-Jul	4	5.8%
Red Fox	*Vulpes vulpes*	27-May	3-Aug	18	26.1%
Kodiak Brown Bear	*Ursus arctos middendorffi*	27-May	13-Jul	6	8.7%
Common name	Scientific name	**2010**			
Eagle spp.	*H. leucocephalus, A. chrysaetos*	26-May	15-Aug	49	55.1%
Merlin	*Falco columbarius*	10-Jul	11-Aug	6	6.7%
Peregrine Falcon	*Falco peregrinus*	22-Jun	22-Jun	1	1.1%
Parasitic Jaeger	*Stercorarius parasiticus*	8-Jun	23-Jul	4	4.5%
Black-billed Magpie	*Pica hudsonia*	26-May	18-Aug	46	51.7%
Common Raven	*Corvus corax*	28-May	18-Aug	15	16.9%
Northern Shrike	*Lanius excubitor*	15-Jul	17-Aug	4	4.5%
Red Fox	*Vulpes vulpes*	30-May	12-Aug	22	24.7%
Kodiak Brown Bear	*Ursus arctos middendorffi*	26-May	17-Aug	6	6.7%
Common name	Scientific name	**2011**			
Eagle spp.	*H. leucocephalus, A. chrysaetos*	28-May	23-Aug	61	67.0%
Merlin	*Falco columbarius*	15-Jun	17-Aug	6	6.6%
Unknown Falcon spp.	*Falco spp.*	1-Jun	22-Aug	3	3.3%
Parasitic Jaeger	*Stercorarius parasiticus*	29-May	27-Jul	10	11.0%
Black-billed Magpie	*Pica hudsonia*	29-May	23-Aug	63	69.2%
Common Raven	*Corvus corax*	24-Jun	23-Aug	18	19.8%
Northern Shrike	*Lanius excubitor*	13-Jun	22-Aug	11	12.1%
Red Fox	*Vulpes vulpes*	8-Jun	11-Aug	11	12.1%
Short-tailed weasel	*Mustela erminea*	17-Jun	21-Aug	2	2.2%
Kodiak Brown Bear	*Ursus arctos middendorffi*	17-Jun	9-Aug	3	3.3%
Common name	Scientific name	**2012**			
Bald eagle	*Haliaeetus leucocephalus*	2-Jun	31-Jul	38	62.3%
Parasitic Jaeger	*Stercorarius parasiticus*	10-Jun	31-Jul	7	11.5%
Black-billed magpie	*Pica hudsonia*	2-Jun	31-Jul	34	55.7%
Common raven	*Corvus corax*	5-Jun	28-Jul	12	19.7%
Red Fox	*Vulpes vulpes*	7-Jun	24-Jul	8	13.1%
Common name	Scientific name	**2013**			
Eagle spp.	*H. leucocephalus, A. chrysaetos*	6-Jun	2-Aug	38	58.5%
Peregrine Falcon	*Falco peregrinus*	27-Jun	1-Aug	2	3.1%
Parasitic Jaeger	*Stercorarius parasiticus*	5-Jul	5-Jul	1	1.5%
Kodiak Brown Bear	*Ursus arctos middendorffi*	8-Jul	8-Jul	1	1.5%
Black-billed magpie	*Pica hudsonia*	6-Jun	28-Jul	43	66.2%
Common raven	*Corvus corax*	7-Jun	26-Jul	7	10.8%

Red Fox	*Vulpes vulpes*	19-Jun	4-Jul	4	6.2%
Common name	Scientific name	**2014**			
Eagle spp.	*H. leucocephalus, A. chrysaetos*	26-May	6-Aug	47	58.0%
Peregrine Falcon	*Falco peregrinus*	28-May	1-Jul	3	3.7%
Parasitic Jaeger	*Stercorarius parasiticus*	29-Jul	29-Jul	1	1.2%
Kodiak Brown Bear	*Ursus arctos middendorffi*	16-Jun	3-Aug	4	4.9%
Black-billed magpie	*Pica hudsonia*	26-May	3-Aug	43	53.1%
Common raven	*Corvus corax*	30-May	3-Aug	7	8.6%
Merlin	*Falco columbarius*	26-Jul	28-Jul	3	3.7%
Red Fox	*Vulpes vulpes*	28-May	7-Aug	19	23.5%
Common name	Scientific name	**2015**			
Eagle spp.	*H. leucocephalus, A. chrysaetos*	25-May	10-Aug	72	75.0%
Peregrine Falcon	*Falco peregrinus*	30-Jun	4-Aug	4	4.2%
Parasitic Jaeger	*Stercorarius parasiticus*	30-May	20-Jul	4	4.2%
Kodiak Brown Bear	*Ursus arctos middendorffi*	12-Jun	1-Jul	5	5.2%
Black-billed magpie	*Pica hudsonia*	24-May	8-Aug	60	62.5%
Common raven	*Corvus corax*	5-Jun	1-Aug	13	13.5%
Merlin	*Falco columbarius*			0	0.0%
Ermine	*Mustela erminea*	2-Aug	7-Aug	3	3.1%
Red Fox	*Vulpes vulpes*	25-May	13-Jul	20	20.8%
Common name	Scientific name	**2016**			
Eagle spp.	*H. leucocephalus, A. chrysaetos*	27-May	6-Aug	78	60.5%
Peregrine Falcon	*Falco peregrinus*	31-May	6-Aug	5	3.9%
Parasitic Jaeger	*Stercorarius parasiticus*	29-May	26-Jul	4	3.1%
Kodiak Brown Bear	*Ursus arctos middendorffi*	7-Jun	18-Jun	4	3.1%
Black-billed magpie	*Pica hudsonia*	26-May	5-Aug	77	59.7%
Common raven	*Corvus corax*	26-May	2-Aug	14	10.9%
Merlin	*Falco columbarius*	12-Jun	25-Jul	3	2.3%
Red Fox	*Vulpes vulpes*	6-Jun	2-Aug	18	14.0%

*****Percent of observation days seen was calculated by taking total observation days seen divided by the total number of observation days. The total number of observation days (24 hour period when one group of people at a study site recorded predators seen) each season, accounting for years when multiple search teams were deployed, equaled: 69 in 2009, 89 in 2010, 91 in 2011, 61 in 2012, 65 in 2013, 81 in 2014, 96 in 2015, and 129 in 2016.

APPENDIX K. Summary of Kittlitz's murrelet chicks found dead on the nest from no apparent cause on Kodiak Island, AK, 2009-2015.

Failed nest**	Date of chick death	Date chick collected	Chick age at death (days post-hatch)	Chick carcass mass (g)	Chick feeding rate (fish/day)	Number of fish deliveries within 24hrs of chick death	Saxitoxin Results (ng/g)		
							Upper GI*	Liver	Kidney
KODKIMU0908	~28-Jun-09	4-Jul-09	~2	N/A*	N/A	N/A	N/A	N/A	N/A
KODKIMU1008	~21-Jun-10	22-Jun-10	~5	67	N/A	N/A	N/A	N/A	N/A
KODKIMU1009	30-Jun-10	10-Jul-10	2	37	2	3	N/A	N/A	N/A
KODKIMU1015	~10-Aug-10	11-Aug-10	~2	31.5	N/A	N/A	N/A	N/A	N/A
KODKIMU1101	11-Jul-11	12-Jul-11	10	88	3.2	6	58.4	N/A	N/A
KODKIMU1107	24-Jun-11	26-Jun-11	7	53	3.5	4	42.2	N/A	N/A
KODKIMU1109	17-Jul-11	N/C*	18	N/A	4.6	7	N/A	N/A	N/A
KODKIMU1110	30-Jun-11	3-Jul-11	7	80.5	4.7	5	12.6	N/A	N/A
KODKIMU1111	23-Jul-11	26-Jul-11	24	127	4.6	7	N/A	N/A	N/A
KODKIMU1112	30-Jun-11	3-Jul-11	3	34	3.0	6	bdl*	N/A	N/A
KODKIMU1113	~4-Jul-11	N/C	~2	N/A	N/A	N/A	N/A	N/A	N/A
KODKIMU1114	11-Jul-11	13-Jul-11	11	123	5.3	8	7.6	N/A	N/A
KODKIMU1201	4-Jul-12	4-Jul-12	4	50	3.67	4	210.3	69	N/A
KODKIMU1206	~29-Jun-12	11-Jul-12	~5	45	N/A	N/A	216	106.4	N/A
KODKIMU1208	28-Jun-12	30-Jun-12	4	~45	2.33	4	52.4	56.3	27.9
KODKIMU1317	22-Aug-13	N/C	14	N/A	2.07	2	N/A	N/A	N/A
KODKIMU1404	27-Jun-14	N/C	~ 5	N/A	6	6	N/A	N/A	N/A
KODKIMU1406	22-Jun-14	N/C	2	N/A	2	4	N/A	N/A	N/A
KODKIMU1408	22-Jun-14	25-Jun-14	1	31	2	3	10.38	12.47	N/A
KODKIMU1410	22-Jun-14	25-Jun-14	5	65.5	3	4	338.05	104.73	N/A
KODKIMU1414	23-Jun-14	N/C	< 1	N/A	0	0	N/A	N/A	N/A
KODKIMU1515	28-Jul-15	4-Aug-15	3	N/A	1	0	N/A	N/A	N/A

*GI – gastrointestinal; N/C – not collected; N/A – not available; bdl – below detectable limits.

**In 2011 chicks were preserved in ethanol when collected and frozen at the end of the field season. Concentrations in upper GI from 2011 chicks likely were falsely depressed because ethanol is used in the extraction of saxitoxin from tissues for testing. Beginning in 2012 a propane freezer was used in the field to freeze chicks as soon as possible after collection.

APPENDIX L. Characteristics of Kittlitz's murrelet nests on Kodiak Island, AK, from 2008 to 2016.

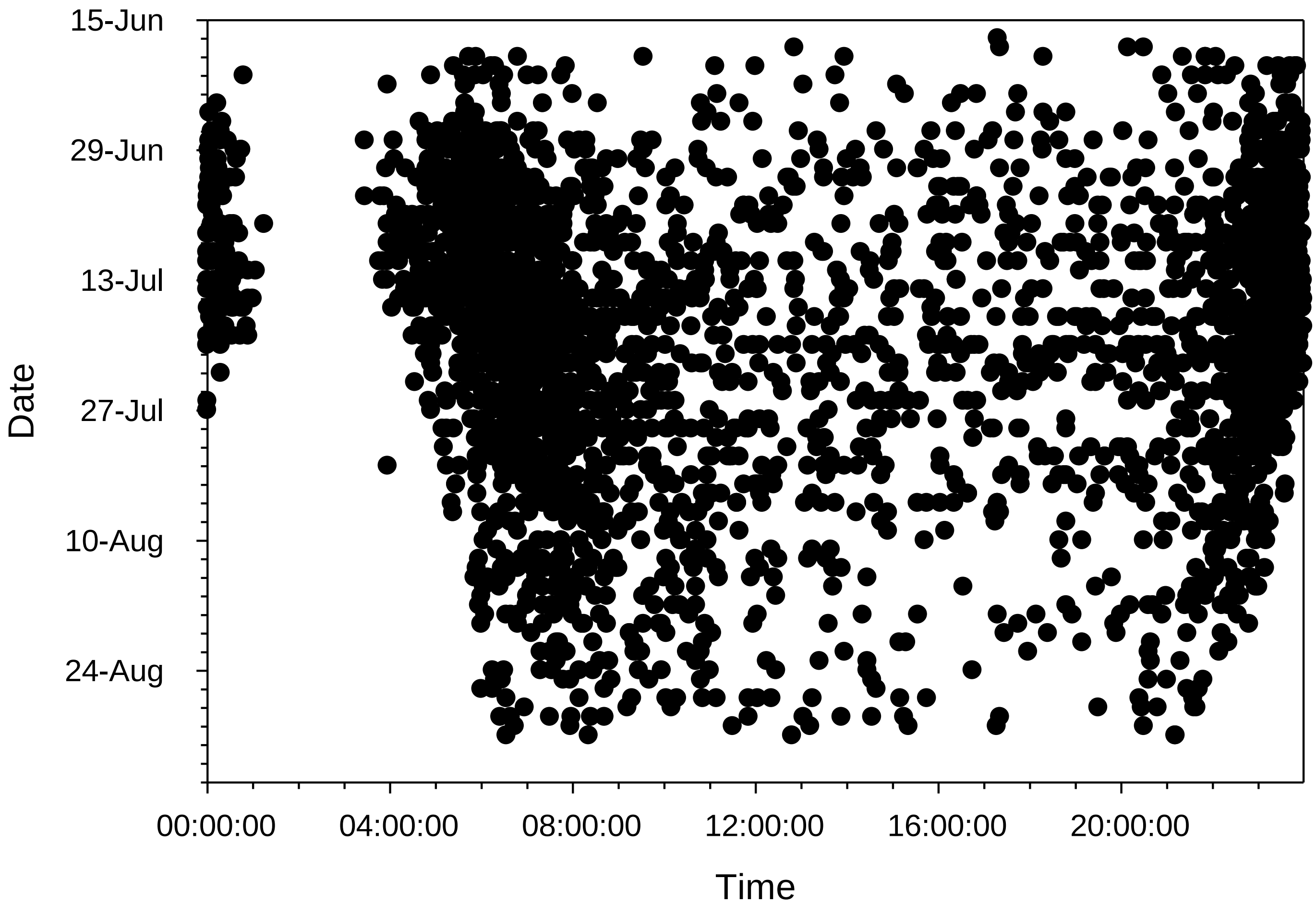
	Year	Elevation (m)	Distance to Ocean (km)*	Slope (degrees)	5m %Veg	25m %Veg	50 m %Veg
Mean							
	2008	394	8.81	30	9	8	9
	2009	355	5.78	29	7	7	8
	2010	308	6.36	28	7	6	7
	2011	308	5.56	29	6	12	16
	2012	302	6.20	29	4	4	5
	2013	317	5.92	35	10	11	12
	2014	327	6.44	36	5	8	9
	2015	328	5.91	35	4	5	5
	2016	323	6.35	33	4	4	4
Max							
	2008	426	10.18	34	20	15	18
	2009	454	9.83	37	32	22	23
	2010	455	10.14	36	33	30	30
	2011	443	9.66	34	15	45	70
	2012	440	10.20	35	30	30	25
	2013	447	10.18	44	32	35	38
	2014	448	10.18	49	20	30	38
	2015	455	10.11	47	12	11	14
	2016	421	10.40	42	9	12	10
Min							
	2008	361	5.44	22	2	1	4
	2009	270	3.51	20	1	0	0
	2010	219	3.96	21	1	1	1
	2011	181	3.80	20	1	1	1
	2012	221	3.87	20	0	1	1
	2013	199	3.50	25	2	2	2
	2014	162	4.24	20	0	0	1
	2015	242	3.61	20	1	1	1
	2016	210	3.56	23	0	0	0
2008-2016 Totals							
	Mean	322	6.17	32	6	7	9
	Max	455	10.40	49	33	45	70
	Min	162	3.50	20	0	0	0

*Distance to ocean was calculated using a straight line distance from the nest to the nearest point on the coast.

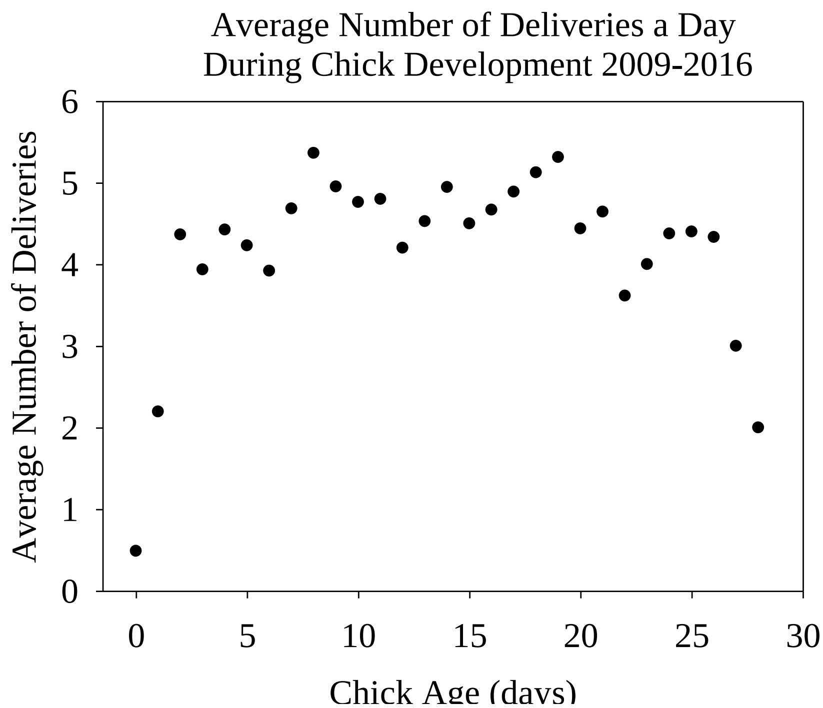
APPENDIX M. Shortest time between subsequent prey deliveries by the same KIMU adult and estimated foraging travel distance (round trip) on Kodiak Island, AK, from 2009-2016. Estimates were based on a single nest each season representing the shortest interval between every other prey delivery, and the average flight speeds for marbled murrelets during radar studies on Kodiak Island, AK (Cragg et al. 2016).

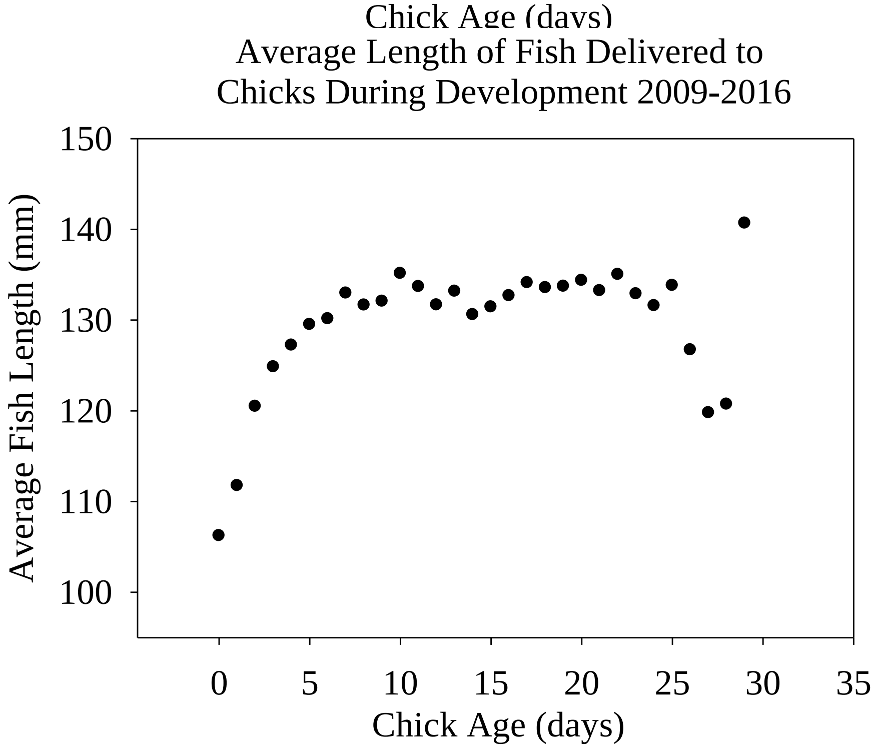
Year	Nest ID	Study Site	Time Away (min)	Travel Distance (km)
2009	KODKIMU0909	Anvil	69	47.73
2010	KODKIMU1005	Kahuna	45	31.13
2011	KODKIMU1111	Kahuna	26	17.98
2012	KODKIMU1212	Kahuna	39	26.98
2013	KODKIMU1308	Anvil	21	14.53
2014	KODKIMU1404	Duncan	30	20.75
2015	KODKIMU1510	Anvil	159	109.98
2016	KODKIMU1601	Duncan	21	14.53
Mean			51.25	35.45

APPENDIX N. Date and time of chick meal provisioning (n=3400 deliveries) by adult Kittlitz's murrelets from 60 camera monitored nests during the 2009-2016 nesting seasons on Kodiak Island, AK.

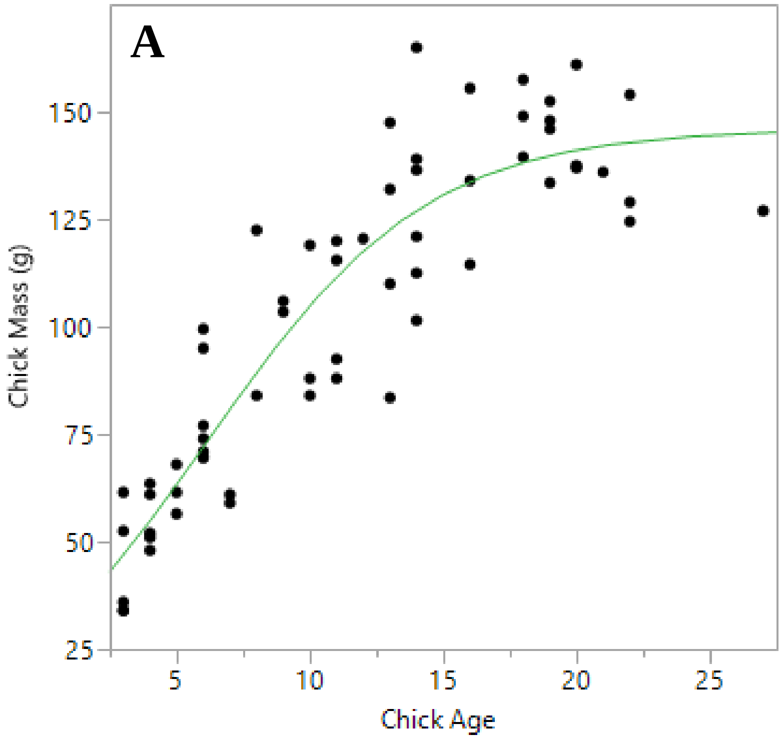


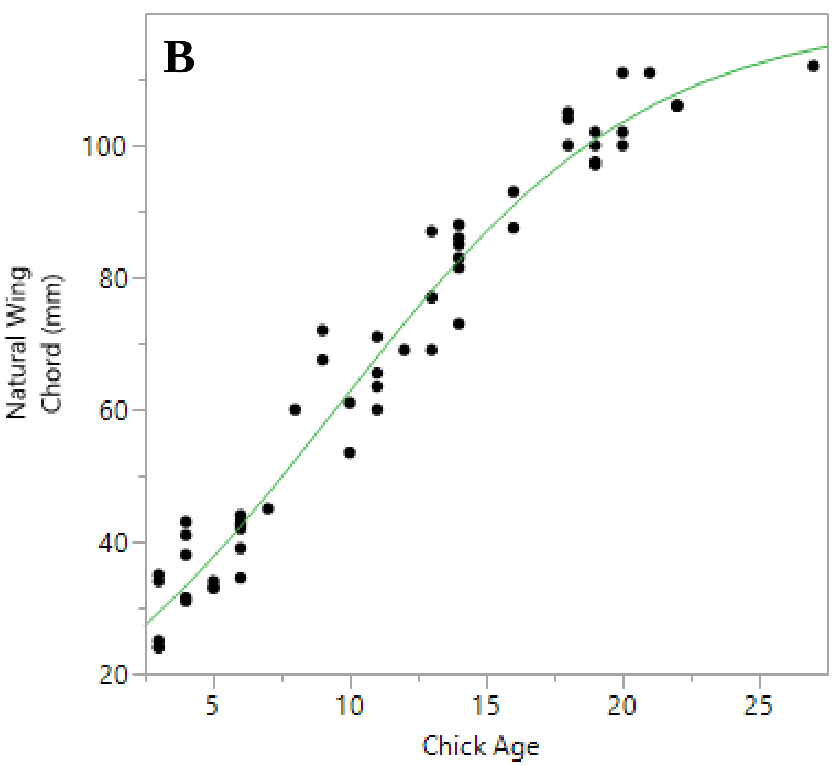
APPENDIX O. Average number of deliveries and average fish length delivered a day at each age of chick development. Fish lengths were estimated using photos from nest cameras. Each fish delivered was recorded as a ratio to adult head length. A head length of 57.3 mm was multiplied by each ratio to obtain an estimated length. Averages are calculated from camera monitored nests during the 2009-2016 nesting seasons on Kodiak Island, AK, from a sample size of 60 chicks and 3422 fish deliveries.





APPENDIX P. Logistic equations are fitted to Kittlitz's murrelet chick growth measurements collected at nests on Kodiak Island, AK, from 2009-2016. Only measurements for chicks with known hatch dates (n=25 chicks) recorded by nest camera images were used. A) Chick age (days) plotted against mass (g) (n=62 measurements), and B) chick age (days) plotted against wing chord (mm) (n=57 measurements).





APPENDIX Q. Kittlitz's murrelet prefledge period and chick provisioning summary for successful nests with complete camera footage from hatch to fledge (n=14) on Kodiak Island, AK, from 2009-2016. Each fish delivered was recorded as a ratio to adult head length. A head length of 57.3 mm was multiplied by each ratio to obtain an estimated length.

Year	n	Prefledge Period	Average Fish Length (mm)	Total fish length	Total Deliveries	Deliveries a day
2009	1	22.0	132.8	11415.2	86.0	3.6
2010	1	22.0	131.5	10653.5	81.0	3.7
2011	2	26.5	135.3	19336.0	142.5	5.4
2012	3	23.7	135.7	13513.3	99.7	4.0
2013	4	21.8	127.5	12534.5	98.0	4.4
2014	1	23.0	125.1	14014.4	112.0	4.7
2016	2	26.5	111.9	11945.1	109.0	4.0
Average		23.6	128.6	13523.1	105.2	4.3

*In 2015 no chicks fledged.